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Seasonal dynamics of zooplankton in Lake Huetzalin, Xochimilco (Mexico City, Mexico)

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ABSTRACT

We quantified the seasonal changes in the zooplankton abundances collected from the Huetzalin Lake (Mexico City, Mexico) for two years (February 2003–January 2004 and then March 2005–February 2006). Selected physicochemical variables (Secchi depth, temperature, pH, conductivity, dissolved oxygen, phosphorus, nitrogen, carbon and chlorophyll *a* concentration) were also measured at the time of zooplankton collection. The data on zooplankton abundances and the physicochemical variables were subjected to multiple correlation analysis and we also derived Shannon–Wiener species diversity index. Secchi depth ranged from 9 to 65 cm. Generally the lake was alkaline (pH 7–12). The conductivity ranged from 500–1000 mS cm^{-1}, while the mean water temperature was 20.5 °C. Dissolved oxygen levels were generally >3 mg L^{-1} and were higher in the winter than warmer months. Nitrates (90–95 μg L^{-1}) and phosphates (.2–.5 mg L^{-1}) indicated that the water was eutrophic. Chlorophyll *a* levels ranged from 143 to 696 μg L^{-1} during the study period. The zooplankton community was dominated by rotifers (46 species), followed by cladocerans (9 species) and there were only two copepod species. The dominant rotifer species were *Brachionus angularis*, *Brachionus calyciflorus*, *Brachionus havanaensis*, *Brachionus quadridentatus*, *Lecane bulla* and *Polyarthra vulgaris*. Rare rotifer species in Lake Huetzalin were *Lecane ohioensis*, *Dicranophorus forcipatus*, *Lecane pyriformis*, *Lindia torulosa*, *Pleurotrocha petromyzon* and *Brachionus durgae*. Highest densities (occasional peaks of 400 ind L^{-1}) of *B. quadridentatus* occurred between April and December, while *B. havanaensis* reached peak densities, during June to October. *B. calyciflorus* reached densities higher than 1240 ind L^{-1} during May–September. Cladoceran and copepod densities in Lake Huetzalin were much lower than that of the rotifers. This study confirmed the earlier findings that Xochimilco system of canals is dominated by rotifers and the crustacean zooplankton have much lower abundances possibly due to predation from fish.

Introduction

Mexico has many hundreds of shallow lakes with an average depth of less than 3 m (De la Lanza and García 2002). The nutrient dynamics and plankton diversity in the shallow lakes are significantly different from those in deep lakes. For example, in shallow waterbodies, nutrient cycling of nitrogen and phosphorus is fairly rapid (Timotius and Goltenboth 1995). Due to their shallow depths, bioturbation suspends high nutrients into the water column.

Lake Huetzalin is part of Lake Xochmilco, a Ramsar Site, which is an ancient lake in the heart of Mexico City that once covered 125,000 ha in the Valley of Mexico. It has now been reduced to a shallow waterbody consisting of many shallow (<2 m) lakes and interconnecting canals, covering 190 ha (Stephan-Otto 2003). Lake Huetzalin also receives waste water from 'Cerro de la Estrella' treatment plant. The canals of Xochimilco are home to several endemic and endangered species. More than 120 bird species have been recorded at this lake. Common fish fauna in the lakes includes *Cyprinus carpio*, *Tilapia niloticus* and *Xiphophorus helleri*. A few individuals of the endemic and currently endangered Axolotl, *Ambystoma mexicanum*, have also been found in this lake (Stephan-Otto 2003). Some of the significant problems of Xochimilco are the deterioration of water quality due to the release of domestic waste water into lake and reduction in water levels. Traditional waste-water treatment processes located close to the lake are not effective in reducing the levels of nitrogen and phosphorus. Therefore the lake is often eutrophic to hypertrophic. Though eutrophic water bodies often have low species diversity, previous studies have shown that the canals of Xochimilco have a high diversity of rotifers (Nandini et al. 2005).

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Zooplankton diversity, good indicator of the health of aquatic ecosystems, is generally high in shallow lakes (Cózar et al. 2003). It is also known that the diversity of rotifers and cladocerans associated with macrophytes is higher than that found in the pelagia or the open waters (Dodson and Frey 2001; Wallace et al. 2006). Lake Huetzalin has a high diversity of macrophytes including *Eicchornia crassipes*, *Pistia stratiotes*, *Junco hydrofytos*, *Nymphaceae mexicana* and *Lemna* sp.

Physicochemical variables such as temperature, pH and dissolved oxygen also regulate the density and diversity of zooplankton (Berzins and Pejler 1987, 1989). Since these variables change throughout the year, it is of considerable interest to quantify changes in the zooplankton community structure through seasonally. A previous study (Nandini et al. 2005) in selected canals of Lake Xochimilco indicates high rotifer diversity (3–4 bits ind^{-1}) with a record of 62 species in 19 families. On the other hand, cladoceran density and diversity were very low. It has been well documented that natural zooplankton abundances are also related to fish production; predation pressure on cladocerans is often high in the presence of larval and juvenile fish (Kerfoot and Sih 1987).

Since quantitative information on the zooplankton diversity for many Mexican shallow lakes is scarce, the aim of this work was to present data on the nutrient and zooplankton dynamics in Lake Huetzalin (Xochimilco) sampled during different seasons.

Methods

Lake Huetzalin, connected to the canals of Xochimilco, is located at 19°17′N and 99°05′W at an altitude of 2240 m mean sea level. The canals of Xochimilco have a surface area of 55,000 m^2 and a maximum depth of 1.5 m. The temperature ranges from 12–20 °C, with rains from May to September. For this study, we selected three sites; the first located at Mitos Island, the second at the pier and the third at the point at which the treated water enters from the 'Cerro de la Estrella' water treatment plant in Iztapalapa, Mexico City (Fig. 1). Zooplankton sampling was done on a monthly basis for two years, from February 2003 to January 2004 and then March 2005 to February 2006.

During the first year we collected zooplankton from macrophytes (1 kg wet weight at each sampling) by vigorously shaking them into 10 L of the lake water and then concentrating the water through a 50-μm mesh for further analyses. From the same sites we also filtered 50 L of lake water from the surface using the same mesh and concentrated and fixed the samples with formalin (10%). During the second sampling period, we collected zooplankton only from the open lake water since we found no significant differences in rotifer richenss in the previous year between macrophyte associated and open water fauna. Zooplankton was identified to species level under compound microscope (Nikon 100–400X) using keys of Koste (1978), Goulden (1968), Smirnov

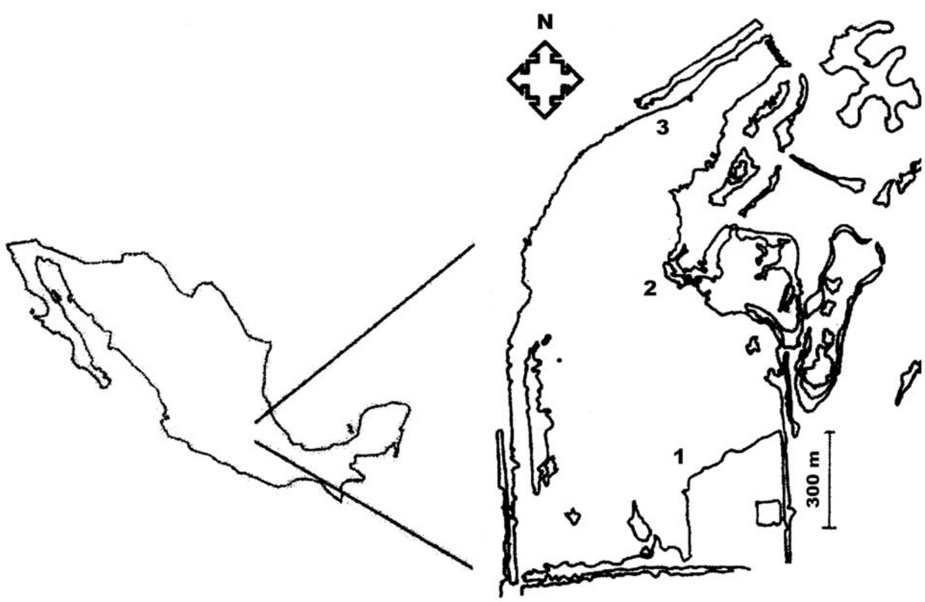

Fig. 1. Map of Lake Huetzalin (Xochimilco, Mexico City) with sampling stations designated. Station 1: Isla de los Mitos, Station 2: Embarcadero and Station 3: Vertederos.

Table 1
Range of selected physicochemical variables (depth, Secchi transparency, temperature, dissolved oxygen, pH and conductivity) measured at the three stations in Lake Huetzalin (Xochimilco, Mexico City) during 2003–2004 and 2005–2006.

Variable	Sampling period					
	February 2003–January 2004			February 2005–March 2006		
	Station 1	Station 2	Station 3	Station 1	Station 2	Station 3
Lake depth (cm)	32–69	31–76	40–100	15–50	25–45	29–55
Secchi disk (cm)	14–30	10–35	25–65	9–35	11–42	12–47
Temperature (°C)	12–38	14–28	16–30	14–24	15–24	18–25
Oxygen dissolved (mg/L)	1.6–12.4	3.7–12	1.6–10.8	1.36–13.6	2.3–10.3	4.8–13.2
pH	7.9–10.5	8.8–10.4	7–8.5	9.2–11.9	6.5–12.1	6.9–10.5
Conductivity (mS cm^{-1})	500–700	500–700	500–1000	590–800	590–716	500–775

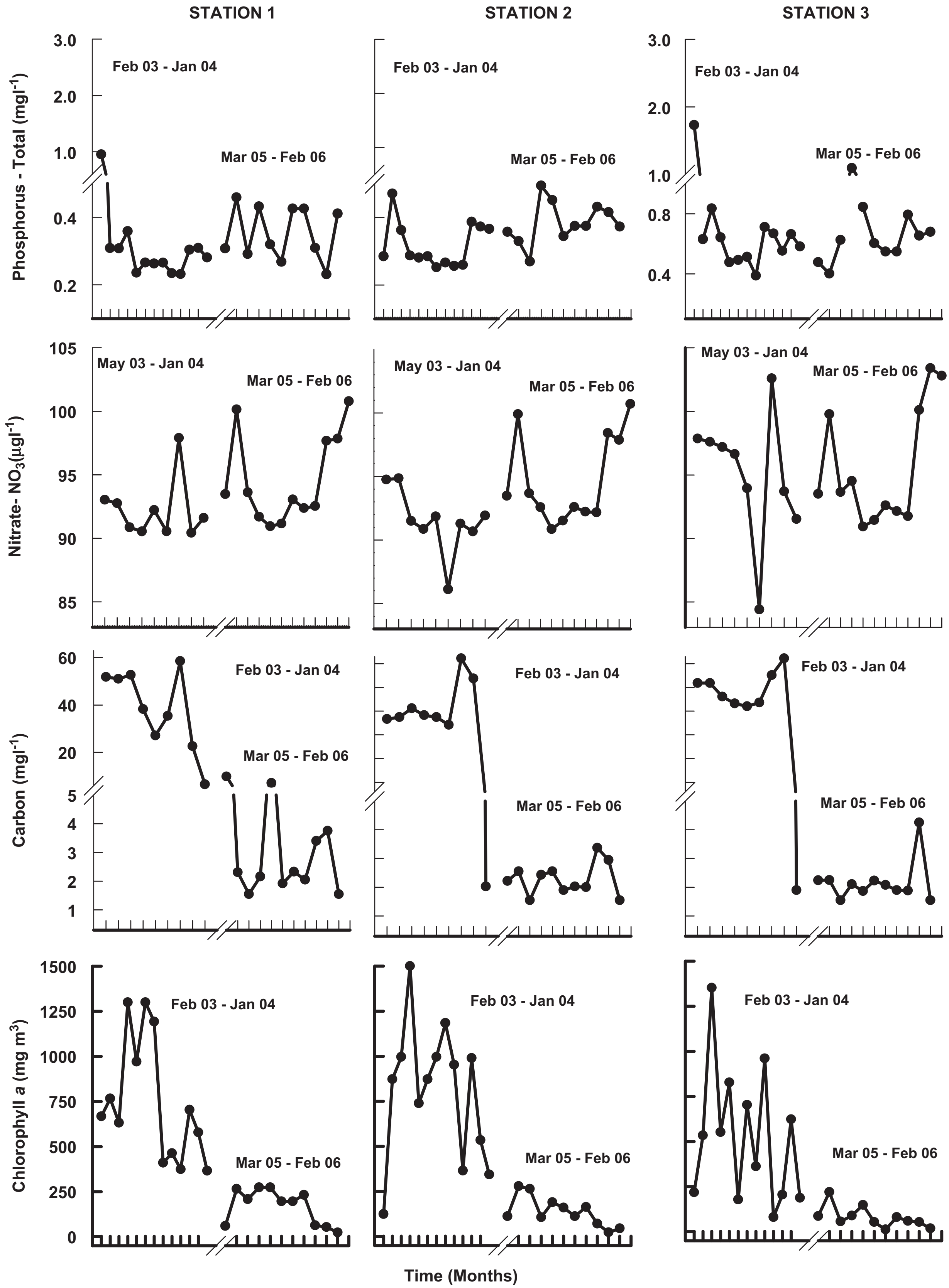

Fig. 2. Data on the selected nutrient levels (phosphorus, nitrogen and carbon) and chlorophyll a from Lake Huetzalin (Xochimilco, Mexico City).

(1974) and Dussart and DeFaye (1995). Quantification of zooplankton was done using Sedgewick Rafter chamber under an inverted microscope (Nikon 600).

Data on physicochemical variables such as Secchi depth, temperature, pH, conductivity, dissolved oxygen, phosphorus, nitrogen, carbon and chlorophyll *a* concentration were also

Table 2
Zooplankton species encountered in Lake Huetzalin (Xochimilco; Mexico City).

Taxonomic group	Sampling period/zone		
Rotifera	M	O	O
Order Ploima	2003–2004	2003–2004	2005–2006
Family: Epiphanidae			
Liliferotrocha subtilis Rodewald, 1940	X	X	X
Family Brachionidae			
Brachionus angularis Gosse, 1851	X	X	X
B. budapestinensis Daday, 1885	X	X	X
B. calyciflorus Pallas, 1766	X	X	X
B. caudatus Barros & Daday, 1894	X	X	X
B. durgae Dhanapathi, 1978			X
B. havanaensis Rousselet, 1911	X	X	X
B. quadridentatus Hermann, 1783	X	X	X
Keratella cochlearis Gosse, 1851	X	X	X
K. tropica Apstein, 1907			X
Platyias quadricornis Ehrenberg, 1886	X	X	X
Family Euchlanidae			
Dipleuchlanis propaptula Gosse, 1886		X	X
Euchlanis dilatata Ehrenberg, 1832	X	X	X
Family Mytilinidae			
Lophocharis salpina Ehrenberg, 1834	X	X	X
Mytilina bisulcata Lucks, 1912	X	X	X
M. mucronata O.F. Müller, 1773	X	X	X
Family Colurellidae			
Colurella obtusa Gosse, 1886	X	X	X
Lepadella ovalis O.F. Müller, 1786	X	X	X
L. patella O.F. Müller, 1786	X	X	X
L. rhomboides Gosse, 1886			X
Family Lecanidae			
Lecane bulla Gosse, 1851	X	X	X
L. closterocerca Schmarda, 1859	X	X	X
L. elegans Harring, 1914			X
L. flexilis Gosse, 1886	X	X	X
L. hamata Stokes, 1896	X	X	X
L. inermis Bryce, 1892	X	X	X
L. ludwigi Eckstein, 1893	X	X	X
L. luna O.F. Müller, 1776	X	X	X
L. obtusa Murray, 1913	X		
L. ohioensis Herrick, 1885	X	X	X
L. pyriformis Daday, 1905.	X	X	
L. quadridentata Ehrenberg, 1832	X	X	X
L. stokesi Pell, 1890	X	X	
L. unguitata Fadeev, 1925	X	X	X
Family: Lindiidae			
Lindia torulosa Dujardin, 1841	X	X	X
Family Notommatidae			
Cephalodella catellina O.F. Müller, 1786			X
Cephalodella gibba Ehrenberg, 1832	X	X	X
Pleurotrocha petromyzon Myers, 1936	X	X	X
Family Trichocercidae			
Trichocerca bicristata Gosse, 1887	X	X	X
T. tenuior Gosse, 1886	X	X	X
Family Synchaetidae			X
Polyarthra vulgaris Carlin, 1943	X	X	X
Family Asplanchindae	X		
Asplanchna brightwellii Gosse, 1850	X	X	X
Family Dicranophoridae			
Dicranophorus forcipatus O.F. Muller, 1786	X	X	
Order Gnesiotrocha			
Family Testudinellidae			
Testudinella patina Hermann, 1783	X	X	X
Family Filiniidae			
Filinia cornuta Weisse, 1847			X
F. longiseta Ehrenberg, 1834		X	X
Cladócera			
Order Anomopoda			
Family Daphniidae			
Simocephalus vetulus Kurz, 1874	X	X	X
Scapholeberis kingi Sars, 1903	X	X	X
Family Moinidae			X
Moina micrura Kurtz, 1820	X	X	X
Family Chydoridae			X
Pleuroxus aduncus Jurine, 1820	X	X	X
Alona rectangula Sars, 1862	X	X	X
Chydorus sphaericus O.F. Müller, 1785	X	X	X
Kurzia latissima Kurz, 1874	X	X	
Family Bosminidae			
Bosmina longirostris (O.F. Müller, 1785)			X
Family Macrothricidae			
Macrothrix triserialis Brady, 1886			X
Copepoda			
Superorder Cyclopoida			
Acanthocyclops americanus Sars, 1863		X	X
Microcyclops rubellus Lilljeborg, 1901		X	X

Data from different stations were combined. X indicates the presence of a particular species in the samples. M = macrophyte zone; O = open water.

obtained in the field or from later analysis in the laboratory using standard techniques (Clesceri et al. 1998).

Zooplankton species diversity indices at each of the stations were calculated using the Shannon–Wiener's formula using the following equations (Krebs 1985):

$$H' = \sum_{i=1}^{s} (Pi)\,(\log_2 Pi)$$

where H' is the Shannon–Wiener Index of diversity, Pi = proportion of S made up of the ith species of zooplankton, total number of zooplankton species. Multiple correlation analysis was done using SPSS and Statistica (vers. 10) statistical software.

Results and discussion

The maximum and minimum depths (100 and 15 cm, respectively) of Lake Huetzalin were recorded during the study period. The water temperature ranged between 16 and 25 °C (mean 20.5 °C). There was one peak of 36 °C which occurred during the dry season and at an extremely shallow depth at Site 1. Secchi transparency ranged from 9 to 65 cm. Generally the lake was alkaline (pH ranging from 7–12). Occasionally pH values dropped below 7.0 (nearly 6.5). Conductivity ranged from 500–1000 mS cm^{-1}. Oxygen levels were generally $>3\,mg\,L^{-1}$ and were higher in the winter than warmer months (Table 1). Once the concentration of dissolved oxygen fell below $.3\,mg\,L^{-1}$ in the month of August at Site 1. Nitrates (90–$95\,\mu g\,L^{-1}$) and phosphates ($.2$–$.5\,mg\,L^{-1}$) indicated that the lake was eutrophic with nitrogen limitation since the N:P ratio is <1. Chlorophyll *a* levels ranged from $696\,\mu g\,L^{-1}$ during 2003–2004 and to $143\,\mu g\,L^{-1}$ during 2005–2006. This corresponded well with the higher levels of carbon (more than a 10-fold increase in the concentrations) in the first as compared to the second period (Fig. 2).

We sampled zooplankton on a monthly basis, although it has been suggested that for tropical waterbodies a sampling duration of a week as is ideal (Lampert et al. 1986). This is often not feasible, especially when different stations and/or different depths are selected (Nandini et al. 2008). Several studies report analyses based on monthly samples which give a general idea about seasonal trends (Nandini et al. 2007; Jimenez-Contreras et al. 2009). In addition, if sampling is conducted for at least two years in tropical systems one can see several changes in the plankton abundances often not visible in short-term studies (Halbach 1979). Thus, in this study it was observed that there was a distinct reduction in nutrient levels, and hence in primary production, which in turn resulted in high species diversity. Productivity and species richness are intricately linked. Normally intermediate levels of productivity allow for greatest species richness (Waide et al. 1999). The nitrogen-to-phosphorus ratio indicates that Lake Xochimilco is a productive system, but in spite of this the richness is quite high in certain sites (Jiménez-Contreras, 2007).

The dominant algal species observed during this study were *Coelastrum astroideum*, *Scenedesmus acutus*, *Scenedesmus opoliensis*, *Scenedesmus westii* and *Pediastrum botyanum*. During the summer months cyanobacteria (mainly *Microcystis* sp.and *Planktothrix* sp.) were present. The zooplankton community was dominated by rotifers (46 species), followed by cladocerans (9 species) and there were only two copepod species (Table 2). Most zooplankton species found in this study were planktonic. There were about 10% more species in the open waters than those associated with the macrophytes. The dominant rotifers species were *B. angularis*, *B. calyciflorus*, *B. havanaensis*, *B. quadridentatus* and *Lecane bulla*, both in the pelagic zone and among macrophytes. On the other hand, *Polyarthra vulgaris* was dominant in the pelagic zone but was absent among macrophytes. The rare rotifer species in Lake Huetzalin were *Lecane ohioensis*, *Dicranophorus forcipatus*, *Lecane pyriformis*, *Lindia torulosa*, *Pleurotrocha petromyzon* and *Brachionus durgae*. The cladocerans, *Pleuroxus aduncus* and *Alona rectangula* were dominant in the pelagic as well as among the plants.

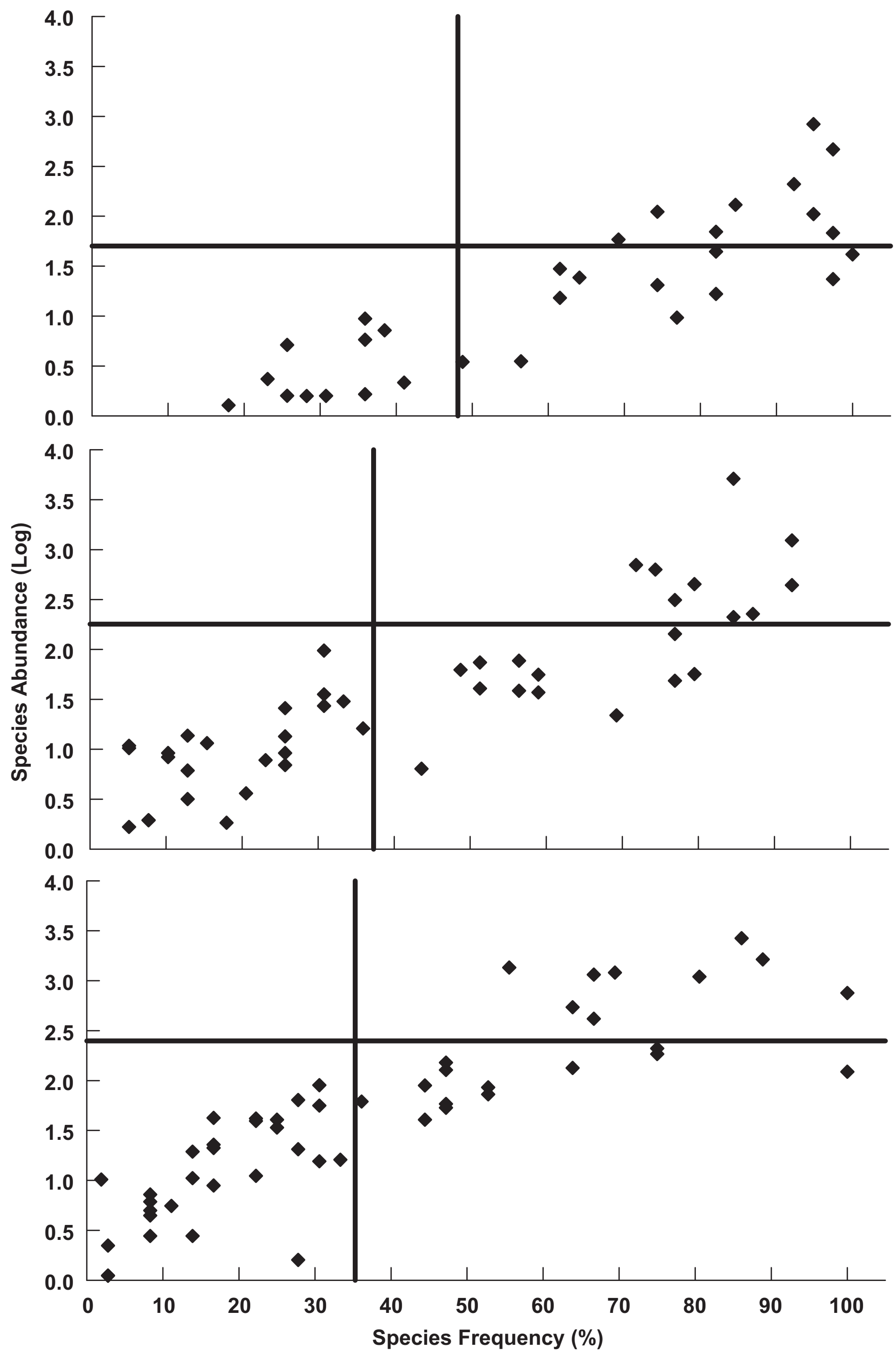

Fig. 3. Olmstead–Tukey association of 54 zooplankton species and their abundances and the frequencies (%).

There was no distinct demarcation in the seasonality of the appearance of many of the species probably because most of them tolerate wide range of temperature, dissolved oxygen and pH (Berzins and Pejler 1987, 1989) and secondly the lake itself had low seasonality (Fig. 3). Two cyclopoid cyclopoids *Acanthocyclops americanus* and *Microcyclops rubellus* were encountered in the lake; the former was dominant during most of the year. Naupliar and early copepodite stages (I–IV) were

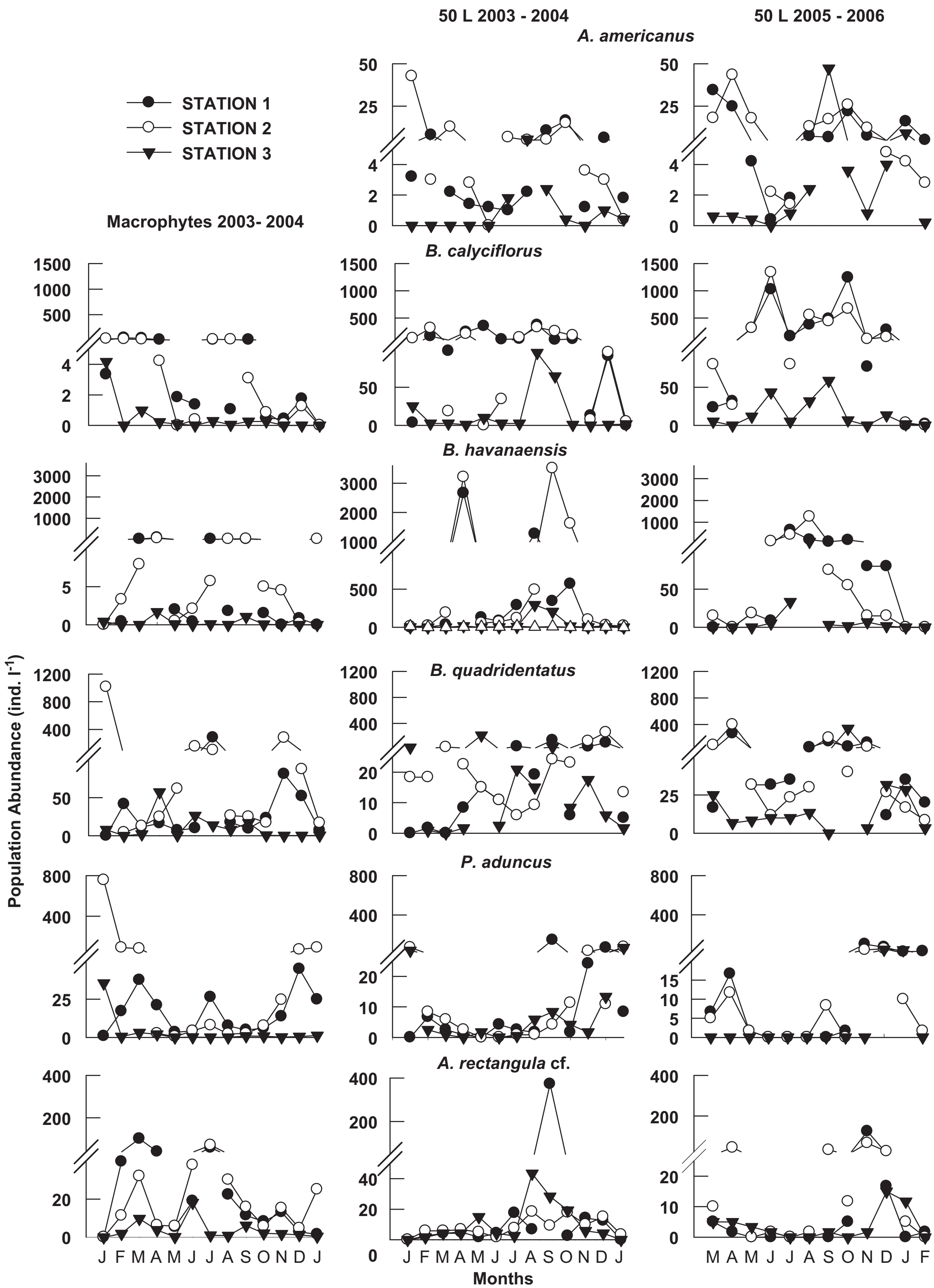

Fig. 4. Seasonal abundances of selected zooplankton species from Lake Huetzalin, (Xochimilco, Mexico City) during 2003–2004 among macrophytes and in the open water) and 2005–2006 (only in the open water).

present at all sites, while copepodite V, and adult males and females were rare.

Data on the monthly fluctuations in the abundances of the dominant zooplankton species are presented in Fig. 4. In general, zooplankton densities were higher in sites 1 and 2 than in site 3. The most abundant rotifer species in the pelagia were *B. calyciflorus*, *B. havanaensis* and among the macrophytes *B. quadridentatus*. The density of *B. quadridentatus* was higher during April–December with occasional peaks of about 400 ind L^{-1}. *B. havanaensis* reached higher peak densities during June–October, in the open waters than among the macrophytes and more so in 2003 than in 2006. *B. calyciflorus*, on the other hand, reached higher densities in 2005 than in 2003, with peak values (1025–243 ind L^{-1}) in the months of May and September. Cladoceran densities in Lake Huetzalin were much lower than those of rotifers. *P. aduncus* and *Alona* cf *rectangula* were more abundant among the macrophytes than in the open waters. Maximal cladoceran densities were observed during January and September. Among the copepods, *A. americanus* reached higher densities than *M. rubellus*. The densities of *A. americanus* were higher in sites 1 and 2 than in site 3 and more so during 2005 than during 2003. Peak copepod densities were observed in April and September.

Multiple correlation analyses among the physicochemical parameters and the abundance of the dominant taxa showed carbon, nitrogen, phosphorus and conductivity influenced the presence of *B. angularis*, *B. calyciflorus*, *T. patina* and *P. aduncus.* Temperature also significantly ($p<.05$, Table 3) influenced the abundance of *B. angularis*, *B. budapestinensis*, *B. havanaensis*, *B. calyciflorus*, *L. bulla* and *C. catellina*, particularly in the pelagic zone. Chlorophyll *a* had a significant impact on more species common in the open water than those found among the macrophytes.

The zooplankton species diversity of the Lake Huetzalin ranged from 1.2 to 3.6 during most of the year (Fig. 5). During 2003–2004, we found a higher species diversity in the macrophytes than in open waters. In general, species diversity was higher in the pelagia in 2005 than in 2003. During October–January period, the species diversity was higher than that from April to June. When the crustacean (cladocerans and adult copepods) density was plotted against the rotifer density, no significant inverse relation existed, indicating the absence of strong suppressive (competitive) abilities of the crustaceans over rotifers in the Lake Huetzalin. There are many reasons for this: (a) firstly in eutrophic waterbodies (where available food (phytoplankon) level is not limiting and competition is intense only under limiting food concentrations (DeMott 1989), (b) secondly, the body size of the crustacean zooplankton is important in their competitive ability over rotifers. Generally large-bodied cladocerans (e.g., *Daphnia*) have much stronger effect than smaller size crustaceans (Gilbert 1988). In our study we did not encounter large-bodied cladocerans (and hence low competition for rotifers) and (c) even when the cladoceran body size is small, competition is predicted to intensify only at high crustacean density (Hurtado-Bocanegra et al. 2002) and in our case we found only very low crustacean densities as compared to rotifers. There was a significant direct relation ($r^2 = .86$, $n = 46$; $p<.01$) between cladoceran and rotifer densities sampled from the macrophytes. This may be attributed to facilitation in the littoral or benthic regions which offer a variety of niches and microclimates for accommodating a large number of taxa (Nandini and Sarma 2001).

Comparison of rotifer diversity from Lake Huetzalin in Xochimilco with the data from other high altitude waterbodies in Mexico indicates some interesting trends. For example, a decade long study on the rotifer diversity from Valle de Bravo (a high altitude reservoir in Mexico) (Ramírez et al. 2002; Nandini et al. 2007, 2008; Jiménez-Contreras et al. 2009) showed that this waterbody was dominated by rotifers and the species diversity varied from $<.5$ to >5.0 depending on the sampling depth and the season. Similarly, Lake Huetzalin is a rotifer-dominant waterbody and the Shannon–Weiner species diversity index was within the range observed for Valle de Bravo reservoir. During an annual cycle in Lake Xochimilco the number of rotifer species was about 60 (Nandini et al. 2005, Jiménez-Contreras et al. 2009); in this study, though we recorded a fewer rotifers (ca. 45 species) they were distributed in more families and we also found a greater diversity of cladocerans. The cladoceran density, on the other hand, was low most probably due to the high densities of fish, which are known to feed selectively on large zooplankton mainly

Table 3
Results of multiple-correlation analyses (r) between the physicochemical parameters and the abundance of the dominant rotifer species from Lake Huetzalin (Xochimilco, Mexico City).

	Dep.	Secc.	pH	Cond	Temp.	DO	Phos.	Nitr.	Car.	Chl *a*
Macrophyte zone										
B. angularis	−.015	**.684**	−.475	−**.619**	−.555	.194	**.662**	**.658**	−**.572**	−.459
B. calyciflorus	−.309	.203	−.282	−**.781**	.061	.182	**.617**	**.583**	−**.599**	−.192
B. havanaensis	−.260	−**.619**	.441	−.159	.441	−.288	−.404	−.377	.387	.417
B. quadridentatus	.269	.098	−.392	−.046	.098	.030	.318	.339	−.289	−.375
L. bulla	−.458	−.129	−.005	−.382	.504	.159	.353	.301	−.393	.038
L. closterocerca	−.259	.028	−.106	−.553	.150	.269	.379	.394	−.455	−.387
T. patina	−.369	.458	−.510	−**.842**	−.001	.339	**.707**	**.736**	−**.621**	−.307
P. aduncus	.083	**.732**	−**.666**	−**.605**	−.461	.168	**.680**	**.750**	−**.579**	−**.643**
A. rectangula	−**.639**	−.433	**.577**	.0102	.273	.050	−.486	−.514	.393	.297
Open water										
B. angularis	.336	.548	−.084	−.061	−**.760**	−.071	.293	.224	−.301	−.366
B. calyciflorus	−.125	−.198	.038	−.169	.448	−.274	.135	.051	−.153	.448
B.havanaensis	−.066	−**.761**	**.606**	.192	**.605**	−.305	−**.582**	−**.575**	.485	**.619**
B. quadridentatus	.541	−.070	−.238	.447	−.298	−.336	−.240	−.294	.318	−.014
K. cochlearis	−.129	.214	−.257	−.212	−.065	−**.634**	−.008	.039	.160	.126
L. bulla	−.100	−**.726**	**.596**	.359	**.675**	−.508	−.493	−.506	.380	.467
P. vulgaris	.151	−.167	.113	−.271	−.113	−.538	−.087	−.040	.070	−.082
P. aduncus	**.772**	.318	−.115	.090	−**.758**	−.047	.225	.229	−.226	−**.617**
A. rectangula	.330	−**.565**	**.592**	.503	−.014	−.311	−**.565**	−**.653**	.452	.296

Dep. = lake depth, Secc. = Secchi transparency, pH, Cond. = conductivity, Temp. = temperature, DO = dissolved oxygen, Phos. = total phosphates, Nitr. = total nitrogen, Car. = carbon, Chl *a* = Chlorophyll *a*. Significant correlations ($p<0.05$) are indicated in bold.

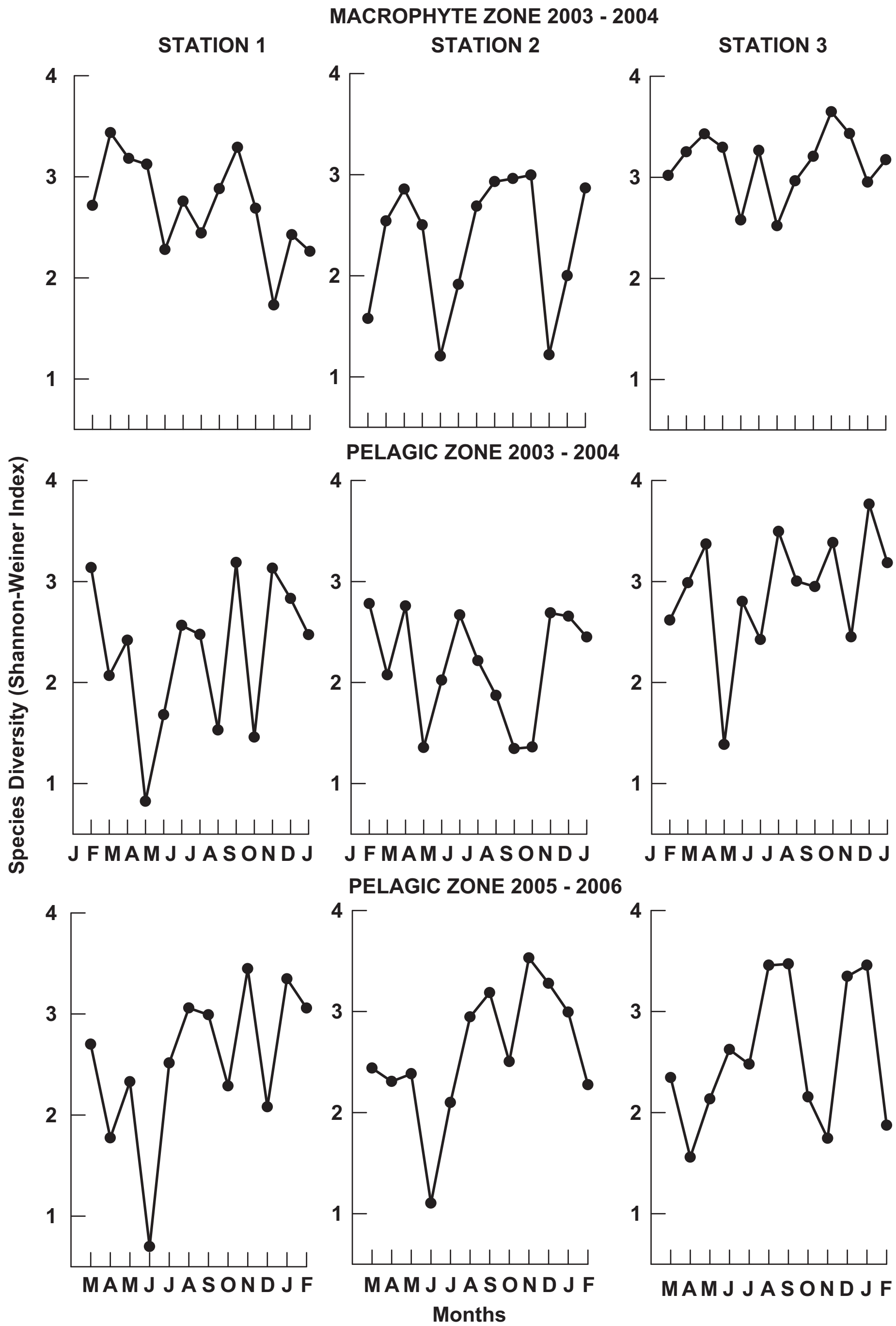

Fig. 5. Seasonal changes in the Shannon–Wiener diversity index of zooplankton species in Lake Huetzalin, (Xochimilco, Mexico City).

crustaceans (Zaret 1980). In addition, the dominant fish predators in this lake either breed throughout the year or are small in size and therefore the feeding pressure on cladocerans must be intense (Stephan-Otto 2003).

In conclusion, the present study confirms the earlier findings (Nandini et al. 2005) that Xochimilco system of canals are dominated by rotifers and the crustacean zooplankton have much lower abundances due to predation from vertebrates and mainly from fish.

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